LONDON-WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA26 | Washwood Heath to Curzon Street

River modelling of the River Rea technical report (WR-004-021)

Water resources

November 2013

ES 3.5.2.26.14

VOL 5

LONDON-WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA26 | Washwood Heath to Curzon Street

River modelling of the River Rea technical report (WR-004-021)

Water resources

November 2013

ES 3.5.2.26.14

High Speed Two (HS2) Limited has been tasked by the Department for Transport (DfT) with managing the delivery of a new national high speed rail network. It is a non-departmental public body wholly owned by the DfT.

A report prepared for High Speed Two (HS2) Limited.

High Speed Two (HS2) Limited,
Eland House,
Bressenden Place,
London SW1E 5DU

Details of how to obtain further copies are available from HS2 Ltd.

Telephone: 020 7944 4908

General email enquiries: HS2enquiries@hs2.org.uk

Website: www.hs2.org.uk

High Speed Two (HS2) Limited has actively considered the needs of blind and partially sighted people in accessing this document. The text will be made available in full on the HS2 website. The text may be freely downloaded and translated by individuals or organisations for conversion into other accessible formats. If you have other needs in this regard please contact High Speed Two (HS2) Limited.

Printed in Great Britain on paper containing at least 75% recycled fibre.

Appendix WR-004-021

Environmental topic:	Water resources and flood risk assessment	WR
Appendix name:	Hydraulic modelling report	004
	River modelling of the River Rea technical report	021

Contents

List of figures

List of tables

1 Introduction

1.1 Structure of the water resources and flood risk assessment appendices

1.1.1 The water resources and flood risk assessment appendices comprise a number of parts. The first of these is a route-wide appendix (Volume 5: Appendix WR-001-000).

1.1.2 Additional specific appendices for each community forum area are also provided. For the Washwood Heath to Curzon Street area (CFA26) these are:

- a water resources assessment (Volume 5: Appendix WR-002-026);
- a flood risk assessment (Volume 5: Appendix WR-003-026);
- a hydraulic modelling report for the River Tame(Volume 5: Appendix WR-004-019);
- a groundwater modelling report for the Bromford tunnel portals (Volume 5: Appendix WR-004-020); and
- a hydraulic modelling report for the River Rea (this Appendix).

1.1.3 Maps referred to throughout the water resources and flood risk assessment appendices are contained in the Volume 5 water resources map book.

1.2 Scope of this assessment

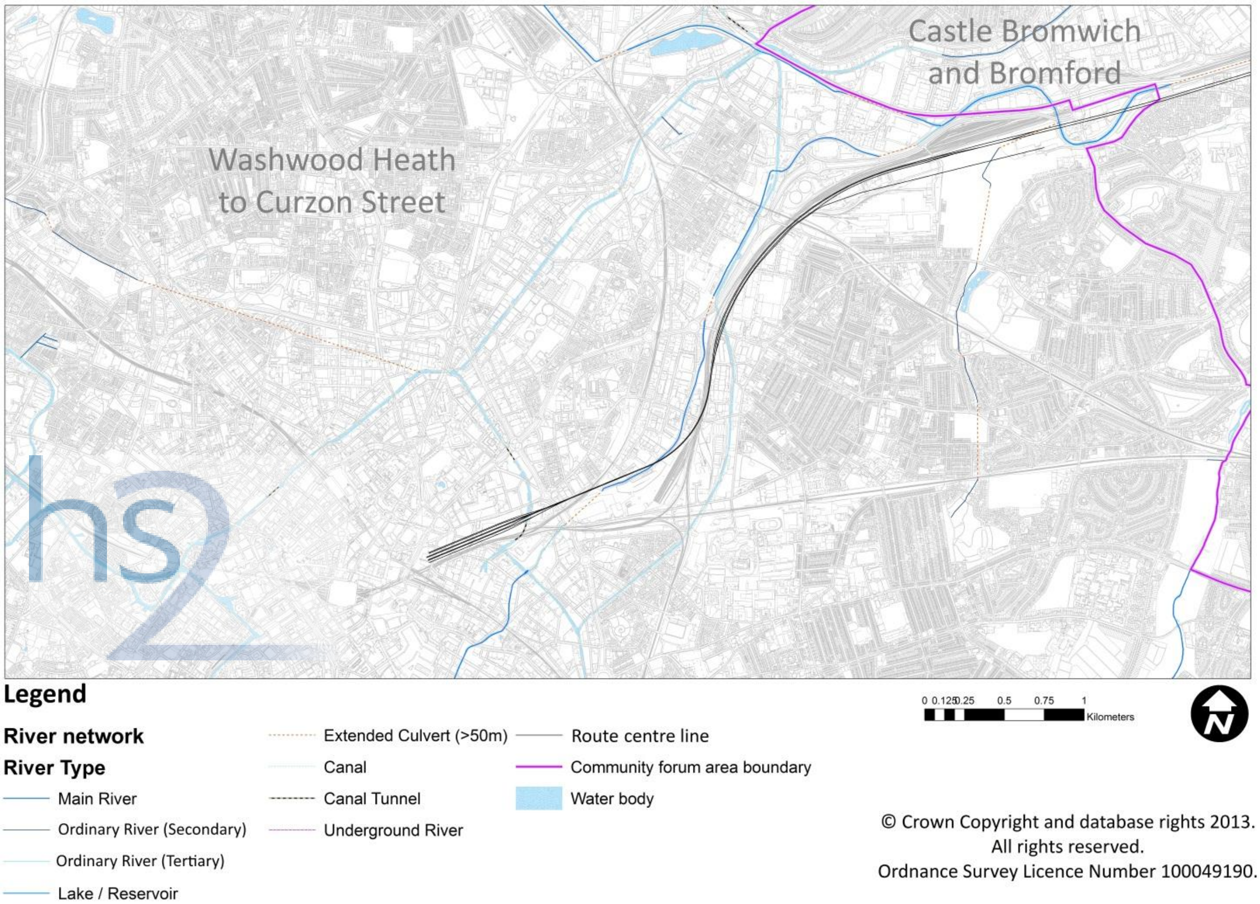
1.2.1 Hydraulic models were constructed to enable an assessment of a) the baseline "as-is" condition and b) with the Proposed Scheme included, to allow for review of impacts on flood risk. In order to assess the scheme the following has been undertaken:

- model a range of return periods from 50% AEP to 1% AEP plus climate change for the pre- and post-development situations to ascertain peak flood levels and flood extent;
- develop mitigation options for post-development; and
- inform land required for the scheme.

1.3 Location

1.3.1 This report focuses on CFA26 Washwood Heath to Curzon Street. The area of consideration is shown in Figure 1.

Figure 1: Washwood Heath to Curzon Street CFA26



2 Overview

2.1.1 The modelling exercise described in the following sections is intended to support the preliminary design of the Proposed Scheme infrastructure within central Birmingham by quantifying the impacts of the development proposals on current and future flood risk from the River Rea.

2.1.2 The hydraulic models were developed to cover the River Rea between Calthorpe gauging station and the confluence with the River Tame at Bromford. Hydraulic modelling of the River Tame is described in Appendix WR-004-019.

2.1.3 The hydraulic models represent the river's main channels, hydraulic structures and heavily urbanised floodplains with a level of detail deemed sufficient to establish extreme water levels and flood flow paths throughout the city centre for pre and post-development scenarios and a range of storm durations and return periods.

3 Sources of data

3.1.1 The following information was used to develop the proposed hydraulic models:

- River Rea Strategic Flood Risk Mapping (SFRM) model (Royal Haskoning, 2010)[1]. The SFRM model covers the River Rea between Longbridge and Bromford, including four tributaries to the Rea: Griffin's Brook, River Bourne, Bourn Brook and Stonehouse Brook. An initial review of the SFRM model (Arup, 2012) identified several shortcomings and limitations to be addressed before it could be used to inform the preliminary design of the Proposed Scheme infrastructure;
- River Rea survey (Maltby Land Surveys, 2008)[2]. Undertaken to inform the SFRM model, the River Rea Survey includes 130 cross-sections between Longbridge and Bromford. Within the area of interest, between Calthorpe and Bromford, the survey includes 49 cross-sections along a 6.9km reach (average cross-section spacing of 142m);
- LiDAR (GeoStore, 2012). Light Detection and Ranging (LiDAR) ground elevation data with 1m resolution (±0.15m tolerance on elevations) was used to define ground levels in the models' 2D domains. The LiDAR data for the entire area of interest was surveyed in 2008;
- OS MasterMap (Ordnance Survey, 2012). MasterMap (vector) data was used to spatially define land uses in the models' 2D domains. Features in the MasterMap data for the entire area of interest were last verified between 2001 and 2012; and
- River Rea relief/overflow (Birmingham City Council, 2012)[3]. Drawings provided by Birmingham City Council (BCC) were used to model the relief channel adjacent to the Saltley Park Industrial Estate. The drawings were supplemented by an informal survey of the relief channel's main features. Therefore this section of the model should be reviewed upon detailed survey (refer to Section 7).

[1] Royal Haskoning, (2010), River Rea Strategic Flood Risk Mapping (SFRM) model, Environment Agency

[2] Maltby Land Surveys, (2008), River Rea survey

[3] Birmingham City Council, (2012), River Rea overflow

4 Baseline model

4.1 Overview

4.1.1 A hydrodynamically linked 1D-2D model (ISIS TUFLOW) was used to represent the river's main channels, hydraulic structures and heavily urbanised floodplains for the pre-development scenario. Inflow hydrographs have been defined for the 50%, 20%, 10%, 5%, 2%, 1.33%, 1% and 0.1% AEPs for the 4.25hr and 10.00hr storm durations. The choice of model allows the representation of the main hydraulic features present in the area of interest and the estimation of their effects on extreme water levels, flood flow paths and flood extents. These are:

- levels and flows along the River Rea, taking into account the channel's geometry and roughness;
- head losses and flows through the river's bridges, culverts and weirs;
- impact of potential blockages at structures;
- water levels and flow paths across the river's floodplains, taking into account ground levels, land uses and other obstructions to flow;
- attenuation of peak flows along the river system; and
- estimation of the impact of changes in the floodplain resulting from the Proposed Scheme infrastructure.

4.1.2 The baseline model covers the River Rea between Calthorpe gauging station and Bromford (confluence with the River Tame). In-bank flows are represented in the 1D domain (ISIS), which draws information from the River Rea SFRM model, the River Rea survey and the River Rea relief channel drawings. Out-of-bank flows are represented in the 2D domain (TUFLOW), which is based on LiDAR and OS MasterMap data and complemented with information from the River Rea SFRM model.

4.1.3 The baseline model (ISIS file BRUM_DEF.dat and TUFLOW file BRUM_DEF.tgc) constitutes a revision/update of the section of the River Rea SFRM model relevant for the Proposed Scheme. It addresses several shortcomings and limitations identified in Arup's initial review (Arup, 2012) and further described in the following sections.

4.2 ID domain (ISIS)

Cross sections

4.2.2 Within the area of interest – between Calthorpe (REA01_6861D) and Bromford (REA01_0) – the River Rea is represented by 49 surveyed cross-sections and 42 replicated and interpolated cross-sections.

4.2.3 Most of the 49 surveyed cross-sections are located at the upstream face of hydraulic structures (bridges, culverts and weirs) and, in the absence of detailed survey, were replicated at the respective downstream faces. Interpolated nodes were used, as required, to increase the model's stability.

4.2.4 The spacing between surveyed cross-sections varies between 17 and 312m, with an average value of 142m within the area of interest (6.9km). Overall, the spacing between cross-sections is deemed adequate and in line with established best practice, where:

- the spacing is no more than 20B, where B is the top width of the channel (~10m); and
- the spacing is no more than 1/2S where S is the mean slope of the river (~0.003m/m).

4.2.5 The eight open sections used to represent the relief channel were derived using LiDAR data and adjusted to match invert levels from the River Rea overflow/relief channel drawings. Existing data from third parties has been used to approximately represent the relief channel. This should be reviewed upon detailed survey (refer to Section 7).

4.2.6 In comparison with the SFRM model, the changes to cross-sectional data were:

- the insertion of panel markers at breakpoints in the channel; and
- the amendment of distances between nodes in line with changes to hydraulic structures.

Hydraulic structures

4.2.7 Within the area of interest, the River Rea main channel comprises the following hydraulic structures:

- 30 bridges-All closed sections of the River Rea extending less than 40m (4B) were modelled in ISIS as 'USBPR' or 'arch' bridges, in accordance with their surveyed geometry. Flow paths over bridge decks were generally modelled in the 2D domain. Exceptions were the 12 bridges extending less than 18m (3 x 2D Grid Size), for which overflows were modelled using 'spill' units in the 1D domain. A weir coefficient of 1.0 (broad crested weir) was used for the 'spill' units representing bridge decks;
- seven culverts-Closed sections of the River Rea extending more than 40m were modelled in the 1D domain as 'rectangular' or 'sprung arch' conduits, in accordance with their surveyed geometry. Overland flow paths above culverts were wholly modelled in the 2D domain. Head loss coefficients of 0.3 and 1.0 were used at the inlet and outlet of conduits, respectively. It is important to highlight that all culverts were modelled considering that their surveyed section shape (generally the upstream face) remains constant through the entire conduit. Downstream invert levels were adjusted assuming a constant slope between surveyed sections. CCTV and level survey of the longer culverts within the area of interest is recommended to confirm or correct the assumptions made (refer to Section 7); and
- one weir-A 'spill' unit with weir coefficient of 1.7 (round nosed weir) was used to model the 1.7m drop in bed level located immediately downstream the Saltley Viaduct (REA01_2286WU).

4.2.8 The River Rea relief channel comprises the following hydraulic structures:

- four culverts - all closed sections along the River Rea relief were modelled in the 1D domain as 'rectangular' or 'sprung arch' conduits, in accordance with the information extracted from the drawings provided by BCC and supplemented by an informal survey of some features. Overland flow paths above all culverts were modelled in the 2D domain and head loss coefficients of 0.3 and 1.0 were used at the inlet and outlet of the conduits. As with the open channel sections, it is important to highlight that the information

available has been used to approximately represent the relief channel but given the quality and accuracy of the data, additional survey work should be undertaken in future stages of the project to improve the accuracy of the model data (refer to Section 7); and

- one weir - a 'spill' unit with weir coefficient of 1.7 (round nosed weir) was used to model the 17.8m wide weir into the relief channel. A crest level of 91.4m AOD was estimated based on the structure's informal survey and the 1m LiDAR data. The weir has been defined using third party data and visual inspection; additional survey work should be undertaken to improve the accuracy of the model data (refer to Section 7).

4.2.9 In comparison with the SFRM model, 12 of the 30 bridges are now represented using 'arch bridge' units as opposed to 'USBPR bridge' units. This method is considered more appropriate where the profile of the bridge is arch-shaped. Also, four of the seven culverts are now represented using 'culvert' units as opposed to 'bridge' units, in order to better represent frictional losses. Between the culverts previously modelled as bridges it is important to highlight structure REA01_3941 REA01_3622, a 319m long conduit previously modelled as a bridge, with significant impact on flood flow routes (refer to Section 4.8).

4.2.10 The Network Rail and Proposed Scheme crossing of the Grand Union Canal, located south-west of the Saltley Park industrial estate, was also modelled as a 1D hydraulic structure in the ESTRY component of TUFLOW (GIS files 1D_nwk_BRUM.shp and 1D_pit_BRUM.shp).

Roughness coefficients

4.2.11 Channel roughness was specified using Manning's 'n' values. A value of 0.02 was used throughout the modelled reach (both open and closed sections). The roughness coefficient was reviewed against site photography (Figure 2) and the assumed value is deemed appropriate for the "plastered masonry" finish found along the modelled reach of the River Rea.

4.2.12 In comparison with the SFRM model, roughness coefficients for the invert of culverts were changed from 0.04 to 0.02, in line with the assessment made for the river's open sections.

4.2.13 Roughness coefficients in the 1D domain were subject to sensitivity testing (refer to Section 6.2).

Figure 2: Typical aspect of the River Rea within the area of interest

4.3 2D domain (TUFLOW)

Extent and cell size

4.3.2 Floodplains are represented in the model's 2D domain (TUFLOW) and extend approximately 350m to both sides of the River Rea, covering a total area of 4.8km² along the modelled reach (GIS files 2D_code_BRUM.shp and 2D_code_BRUM_ExtendedDomain.shp).

4.3.3 In comparison with the SFRM model, the revised 2D domain covers an additional area of 0.2km² near Washwood to contain the entire flood extents for events with return period up to 0.1% AEP.

4.3.4 As in the SFRM model, the proposed 2D domain uses a grid size of 6m, which is considered sufficient to represent flood flow routes along the roads within the area of interest.

Topography

4.3.5 LiDAR data with 1m resolution (refer to Section 3) was used to define ground levels across the 2D domain (GIS files 2D_zpt_BRUM_6m_LiDAR1m.shp and 2D_zpt_BRUM_6m_ExtendedDomain.shp). The ground levels in the updated model were found to differ from those in the original SFRM model by between -1.54 and 1.16m, with an average difference of -0.05m.

4.3.6 LiDAR elevations were complemented with more accurate information in the following areas:

- bridge decks and headwalls (GIS files *2D_zsh_BRUM_Bridges.shp* and *2D _zln_BRUM_Headwalls.shp*). For the 18 bridges extending more than 18m (3 x 2D grid size) where overflows were modelled in the 2D domain, the LiDAR data (often matching river bed/water levels) was amended using deck and parapet levels from the River Rea survey;
- Grand Union Canal (GIS file *2D_zln_BRUM_Canal.shp*). Crest levels for the embankment between the River Rea and the Grand Union Canal near the Heartlands Parkway were amended in accordance with information from the SFRM model;
- flood defences (GIS file *2D_zln_BRUM_Defences.shp*). Crest levels for flood defences located at the upstream section of the modelled extent (*REA01 _6748-REA01_6268*) and at Fazeley (*REA01_4354-REA01_4131*) were also amended in accordance with information from the SFRM model;
- building thresholds (GIS files *2D_zsh_BRUM_Buildings.shp* and *2D_zln_BRUM_ Buildings*.shp). For 55 buildings adjacent to the River Rea where filtering issues significantly compromised the accuracy of the LiDAR data, ground levels were amended to threshold levels estimated from adjacent roads. In addition, similarly to the SFRM model, levels along building walls adjacent to the River Rea were raised by 600mm to more accurately reflect likely threshold levels; and
- stability patches (GIS file *2D_zsh_BRUM_StabilityPatches.shp*). A stability patch was used to remove false ridges in the LiDAR data which were causing unrealistic flow patterns and

model instability near the railway viaduct over the A4540 in Fazeley (*REA01_4038-REA01_3941*).

Land use and floodplain roughness

4.3.7 Floodplain roughness was specified using Manning's 'n' values. OS MasterMap data was used to establish land uses and spatially assign roughness coefficients across the 2D domain (GIS files 2D_mat_BRUM.shp and 2D_mat_BRUM_ ExtendedDomain.shp). The following Manning's 'n' values were attributed to the 14 main land uses identified within the area of interest:

Table 1: Land uses and roughness coefficients (TUFLOW file BRUM_DEF.tmf)

Land Use	Manning's 'n'
Buildings and structures	0.500
Scrub	0.200
Rough grassland	0.150
Gardens	0.100
Coniferous trees	0.080
Non coniferous trees	0.080
Heath trees	0.080
Orchards	0.080
Rail infrastructure	0.080
Grass	0.040
Water features	0.020
Concrete pavement	0.017
Paths	0.017
Roads	0.017

4.3.8 In addition, three patches of very high roughness were used to improve model stability and prevent the occurrence of negative depths in the 2D domain (GIS file 2D_mat_BRUM_StabilityPatches.shp). A Manning's 'n' of 0.5 was used for the stability patches.

4.3.9 Roughness coefficients in the 2D domain were subject to sensitivity testing (refer to Section 6.2).

4.4 Boundary conditions

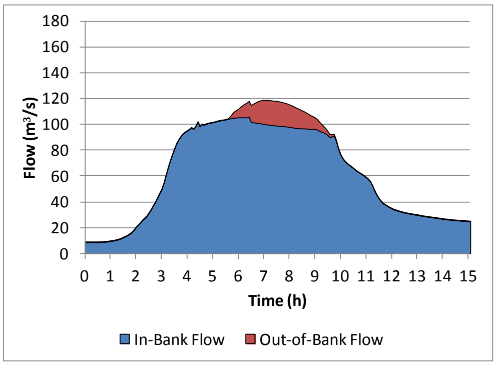
Upstream boundaries (hydrology)

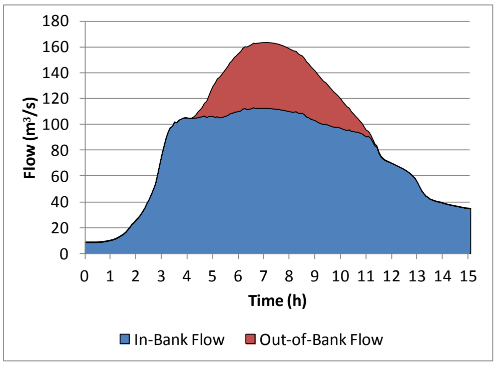
4.4.2 The proposed baseline model has three upstream inflow boundaries. These are:

- REA01_6861D. This is the upstream end of the proposed baseline model, located at

Calthorpe gauging station. Inflows at this node were extracted from the SFRM model and include flows from the 1D and 2D domains, as shown in Figure 3. A review of the SFRM hydrology has been undertaken and appended to this modelling report;

Figure 3: 1% AEP and 0.1% AEP (4.25 hour duration) hydrographs at Calthorpe gauging station (REA01_6861D)





-

- LAT1. Similarly to the SFRM model, this inflow was modelled as a FEH boundary with catchment area of 8.02km², urban extent of 0.3626 and percentage runoff of 64.56. Inflows from this boundary condition are dispersed along 6 points between *REA01_6486* and *REA01_4038*; and
- LAT0. Similarly to the SFRM model, this inflow was modelled as a FEH boundary with catchment area of 4.84km², urban extent of 0.3826 and percentage runoff of 64.03. Inflows from this boundary condition are dispersed along six points between *REA01_3038* and *REA01_581*.

4.4.3 Inflows were generated for events of 50%, 20%, 10%, 5%, 2%, 1.33%, 1% (with and without climate change) and 0.1% AEPs for storms durations of 4.25 and 10.00 hours (ISIS files BRUM_0002yr_04hr.ied to BRUM_1000yr_04hr.ied and BRUM_0005yr_10hr.ied to BRUM_ 1000yr_10hr.ied). The two storm durations adopted are appropriate for the catchment but may not necessarily represent the critical storm duration for all scenarios or return periods. Model results appear to be relatively insensitive to storm duration with the exception of the 1% AEP + CC event. Further analysis of storm duration should be undertaken in future stages of the project (refer to Section 7). Defining the critical storm duration appears particularly important for the 1% AEP (with climate change) event, where extreme water levels along the main channel are significantly higher for the 10.00 hours storm than for the 4.25 hours event (refer to Section 4.8).

Downstream boundary

4.4.4 Results from a model of the River Tame (Arup, 2012) indicate that water levels at the confluence with the River Rea (REA01_0) vary between 86.7m AOD (50% AEP) and 89.7m AOD (0.1% AEP). As a joint probability analysis of flows on the Rea and the Tame was outside the scope of this stage of modelling, a fixed water level of 88.2m AOD was adopted for the proposed baseline model. It is important to highlight that without the benefit of a joint probability study, it is not possible to define the likelihood of extreme events happening in both rivers simultaneously, and it is recommended that this is investigated as the design progresses (refer to Section 7). The downstream boundary condition (water level) was subject to sensitivity testing (refer to Section 6.3).

1D-2D connections

4.4.5 The 1D (ISIS and ESTRY) and 2D (TUFLOW) domains are linked by water level and flow (HX/SX) boundaries and connection (CN) lines (GIS files 1D_ISIS_BRUM.shp and 2D_hx_BRUM.shp, 1D_nwk_BRUM.shp and 1D_sx_BRUM.shp and TUFLOW file BRUM_DEF.tbc). The areas excluded from the 2D domain (GIS file 2D_bc_BRUM.shp) are consistent with the channel widths in the ISIS model.

4.4.6 In comparison with the SFRM model, the following changes were introduced to the 1D-2D connections:

- interpolated nodes were removed/added (in both domains) in order to resolve instability issues;
- 1D-2D connections surrounding the weir immediately downstream the Saltley Viaduct (REA01_2286WU) were corrected; this resulted in a better representation of flow patterns around the hydraulic structure;
- extended HX lines (TUFLOW) were used at the upstream and downstream ends of the modelled reach and connected to the respective boundary nodes (ISIS) in order to improve the representation of flow transfer between the 1d and 2d models; and
- the Network Rail and Proposed Scheme crossing of the Grand Union Canal, located south-west of the Saltley Park industrial estate, was modelled as a 1D hydraulic structure (ESTRY).

4.4.7 In addition, the 'zlines' used in the SFRM model to represent top-of-bank levels by interpolating elevations between surveyed cross-sections were removed. As most surveyed sections are located at the upstream faces of structures (bridges and culverts) and represent the associated wing and headwall elevations, the surveyed levels were deemed to misrepresent river bank levels across the generally long distances between cross-sections. LiDAR data was used to estimate bank levels instead, except at riverside buildings where filtering issues were identified in the LiDAR data. The representation of bank levels in the model has been improved using the best available data but further accuracy could be achieved by undertaking bank top survey, which is recommended for future stages of the project (refer to Section 7). Top-of-bank levels were subject to sensitivity testing (refer to Section 6.4).

4.5 Model stability and runtime parameters

4.5.1 The following departures from recommended/default values of runtime parameters were used in ISIS and TUFLOW in order to improve the model's performance and stability:

- cell wet/dry depth. A value of 0.01m was used for the cell wet/dry depth (TUFLOW);
- height of dummy vertical wall (dflood). A value of 10m was used for the height of dummy vertical wall added to the top of each river cross-section (ISIS) in order to prevent model instability (default value is 3m). However, this value is much lower and closer to the default value than that used in the SFRM model (75m);
- minimum flows. Minimum flows of 9.0 m^3/s (17% of the 50% AEP peak flow), 0.5 m^3/s (10%) and 0.5m^3/s (18%) were used for the model's upstream boundaries (ISIS): REA01_6861D, LAT1 and LAT0, respectively, in order to ensure stable initial conditions. A constant flow of 1.5m^3/s was added (ROF_0815IH) and abstracted (ROF_0000A) to/from the River Rea relief channel in order to prevent model instability;

- stability patches. As described in previous sections, stability patches (GIS files 2D_zsh_BRUM_StabilityPatches.shp and 2D_mat_BRUM_ StabilityPatches.shp) were used to remove false ridges and locally increase roughness values (TUFLOW) in order to prevent model instability;
- top slots. Top slots using the recommended values for distance below soffit and total height (ISIS) were used in some culverts in order to improve the model's performance. Top slots enable the (cross-sectional) surface width of conduits to reduce gradually and aid the transition from free surfaced to surcharged flow; and
- water level and flow tolerances (htol and qtol). Tolerances of 0.02 were used for water levels and flows (ISIS). While the default of 0.01 does not render the model unstable, the proposed values prevent non-convergences in the 1D domain (for the high return periods) without affecting the results.

4.5.2 Time steps of 0.5s (1D domain) and 1.0s (2D domain) were used in all simulations. The selected time steps are lower than the recommended values of 1.5s and 3.0s (6m grid), but are necessary to prevent model instability in some scenarios and return periods.

4.6 Baseline model performance

4.6.1 Typical runtime convergence bitmaps (for the 50% AEP and 0.1% AEP with 4.25 hours duration storm events) are shown in Figure 4. The graphics show that flow and level changes between time steps are within the specified tolerance throughout the simulation, indicating a healthy model.

4.6.2 Mass balance checks were undertaken to ensure the model is not gaining or losing inappropriate amounts of volume. Peak and final mass errors for each simulation are summarised in Table 2. As shown, mass errors are below the typical threshold of 1%, indicating a healthy model.

Figure 4: 50% AEP and 0.1% AEP (4.25h duration) convergence bitmaps (baseline model)

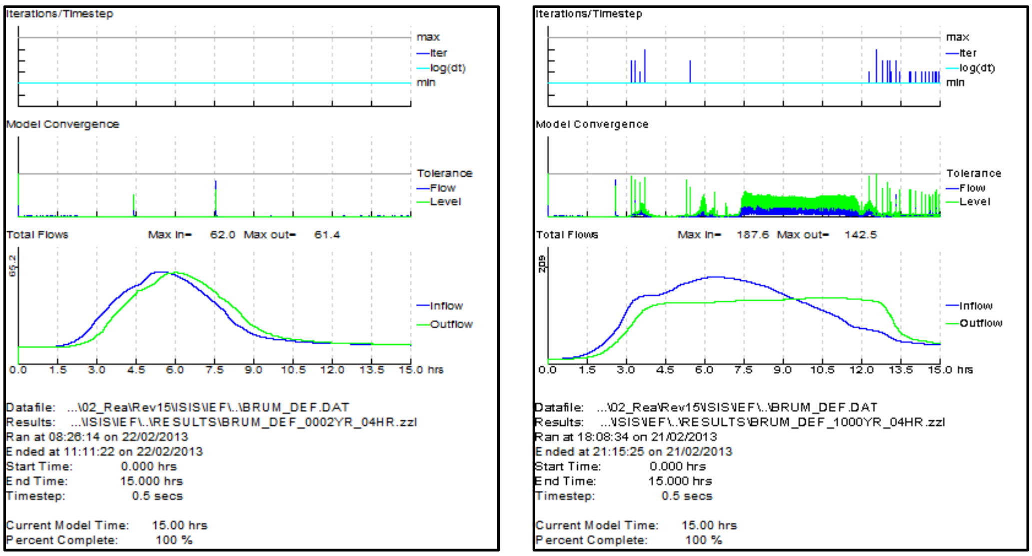


Table 2: Summary of mass errors (baseline model)

Simulation	Peak Mass Error (%)	Final Mass Error (%)
Storm duration of 4.25 hours:		
50% AEP	-0.69	0.00
20% AEP	0.82	-0.03
10% AEP	-0.67	-0.04
5% AEP	0.77	-0.04
2% AEP	-0.74	0.03
1.33% AEP	-0.79	0.02
1% AEP	-0.73	0.00
1% AEP + CC	-0.82	-0.09
0.1% AEP	-0.79	-0.21
Storm duration of 10.00 hours:		
20% AEP	-0.80	-0.03
10% AEP	-0.69	-0.04
5% AEP	0.94	-0.04
2% AEP	-0.77	0.02
1.33% AEP	-0.83	0.02
1% AEP	-0.75	-0.01
1% AEP + CC	-0.62	0.24
0.1% AEP	-0.74	-0.25

4.7 Baseline model results

4.7.1 The baseline model was used to simulate return periods events of 50%, 20%, 10%, 5%, 2%, 1.33%, 1% (with and without climate change) and 0.1% AEP for storms durations of 4.25 and 10.00 hours. The estimated flood extents for key return periods are shown in the appended drawings.

4.7.2 In comparison with the SFRM model, the proposed baseline model shows significant changes to the previously estimated water levels and flood extents. These are mostly due to:

- relief channel. The River Rea relief channel contributes to the reduction of flows, water levels and flood extents between nodes REA01_ 1888D and REA01_1139D, diverting up to 3.4 m^3/s (10% AEP, 10 hours) and 20.1m^3/s (0.1% AEP, 10 hours) through a route overlooked in the SFRM model;
- culverts. The four culverts previously modelled as bridges introduce significant head losses that were underestimated in the SFRM model. The 319m long culvert between nodes REA01_3941 and REA01_3622 is particularly important as it now causes a greater restriction to flow thereby reducing flooding downstream of the culvert at Saltley Park

industrial estate and increasing flooding upstream (between nodes REA01_4131 and REA01_ 3941), significantly affecting the estimated flood levels and extents;

- roughness coefficients. The reduction of roughness coefficients at the invert of culverts from 0.04 to 0.02 is translated into reduced head losses along the 3 conduits included in the SFRM model. The effects on flood levels and extents are particularly relevant at the longer culverts, between nodes REA01_2264 and REA01_2097 (167m) and REA01_443 and REA01_190 (253m); and
- downstream boundary. The proposed downstream level of 88.2m AOD is 0.3m lower than the level used in the SFRM model. As detailed in Section 6.3, the revised downstream boundary condition is not expected to affect levels beyond (upstream) node REA01_2286WD (weir immediately downstream the Saltley Viaduct).

4.8 Critical storm duration

4.8.1 In relation to the different storm durations, changes to peak water levels are deemed negligible for all return periods apart from the 1% AEP with climate change, with peak water levels varying up to 0.03m (20% AEP), 0.01m (5% AEP), 0.10 (1% AEP without climate change) and 0.08m (0.1% AEP). For the 1% AEP with climate change storms, changes in peak water levels vary up to 0.44m, with an average value of 0.16m. *Results suggest a more detailed critical storm duration analysis is not required for the 20%, 5%, 2%, 1.33%, 1% (without climate change) and 0.1% AEP events, but strongly recommended for the 1 in 1% AEP with climate change event.*

5 Post-development model

5.1 Overview

5.1.1 The Proposed Scheme model (ISIS file BRUM_HS2.dat and TUFLOW file BRUM_HS2.tgc) is a development of the proposed baseline model (refer to Section 4) and considers the following changes to the River Rea in Birmingham:

- River Rea diversion. The Proposed Scheme will require a small diversion of the River Rea's main channel between nodes REA01_3329 and REA01_3103. While maintaining the existing channel geometry, the diversion will increase the river length by 15m within the above mentioned reach (GIS files 1D_ISIS _BRUM_HS2.shp and 2D_hx_ BRUM_HS2.shp and TUFLOW file BRUM_HS2.tbc). The area excluded from the 2D domain was updated in accordance with the proposed changes (GIS file 2D_bc_BRUM_HS2.shp) and the existing channel was removed from the model's topography (GIS file 2D_zsh_BRUM_HS2.shp);
- relief channel diversion. The Proposed Scheme will also require the diversion of the River Rea's relief channel. The proposed layout will be approximately 130m shorter than the existing layout with the total culverted length reduced from 493m to 372m (refer to GIS and TUFLOW files in River Rea diversion above);
- Washwood Heath depot. The Washwood Heath depot comprises significant earthworks (cut and fill) along the right floodplain of the River Rea, between nodes REA01_2875 and REA01_0 (GIS file 2D_zpt_BRUM_6m_HS2.shp). This area also includes new flood defence walls (GIS file 2D_zln_BRUM_ HS2.shp) designed to be sufficiently high to prevent overtopping in the 0.1% AEP; and
- Grand Union Canal. The Proposed Scheme's crossing of the Grand Union Canal (Saltley canal underbridge) was also included in the post-development model. The proposed bridge, with 37m span, shall have the same soffit level as the existing Birmingham and Derby Line bridge of 94.4m AOD. The proposed bridge was modelled as a layered flow constriction (refer to GIS file 2D_lfc_BRUM_HS2.shp).

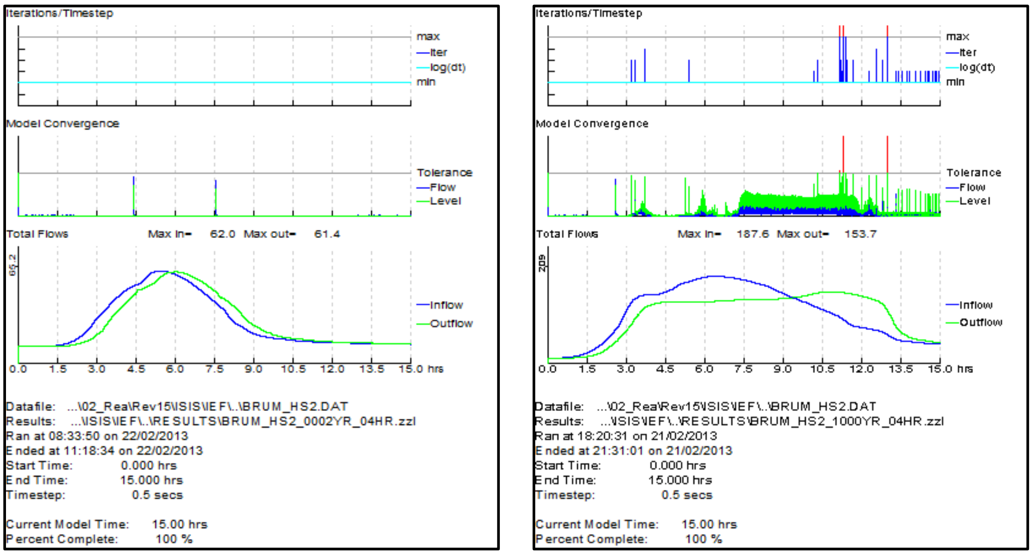
5.1.2 Details of the proposed infrastructure are presented in drawings CT-06 of the Volume 2 Map Book.

5.1.3 Similarly to the baseline model, the post-development model was used to simulate return periods events of 50%, 20%, 10%, 5%, 2%, 1.33%, 1% (with and without climate change) and 0.1% AEP events for storms durations of 4.25 and 10.00 hours.

5.2 Proposed scheme model performance

5.2.1 Typical runtime convergence bitmaps (for the 20% AEP and 0.1% AEP events with 4.25 hours duration) are shown in Figure 5. The graphics show that flow and level changes between time steps are generally within the specified tolerance throughout the simulation (excluding a few isolated episodes of poor model convergence), indicating a healthy model.

Figure 5: 50% AEP and 0.1% AEP (4.25 hour duration) convergence bitmaps (post-development model)



5.2.2 Mass balance checks were undertaken to ensure the model is not gaining or losing inappropriate amounts of volume. Peak and final mass errors for each simulation are summarised in Table 3 below. As shown, mass errors are well below the typical threshold of 2%, indicating a healthy model.

Table 3: Summary of mass errors (post-development model)

Simulation	**Peak mass error (%)**	**Final mass error (%)**
Storm duration of 4.25 hours:		
50% AEP	-0.62	0.00
20% AEP	-0.78	-0.03
10% AEP	-0.76	-0.04
5% AEP	-0.76	-0.04
2% AEP	-0.77	0.03
1.33% AEP	-0.82	0.02
1% AEP	-0.77	0.00
1% AEP + CC	-0.76	-0.08
0.1% AEP	-0.77	-0.21
Storm duration of 10.00 hours:		
20% AEP	-0.71	-0.03
10% AEP	-0.74	-0.04
5% AEP	0.71	-0.04
2% AEP	-0.70	0.02
1.33% AEP	-0.69	0.02
1% AEP	-0.72	0.00

Simulation	Peak mass error (%)	Final mass error (%)
1% AEP + CC	-0.68	0.26
0.1% AEP	-0.57	-0.24

5.3 Post-development model results

5.3.1 As summarised in the tables and figures below, results confirm that the preliminary proposals will not have an adverse impact on the area's flood risk up to the design return period of 1% AEP (with climate change), with changes in peak water levels ranging between ±0.04m and a negligible (~0.01m) average (absolute) change. For the 0.1% AEP estimated changes in peak water levels range between -0.03 and 0.46m, with an average (absolute) change of 0.08m. The estimated post-development flood extents for the 5% AEP and 1% AEP plus CC event are in Volume 5: Map book WR-05 and WR-06..

Table 4: Increase in water levels due to Proposed Scheme

Simulation	Increase in peak water levels (m)	
	Range	Average
Storm duration of 4.25 hours:		
50% AEP	0.00 to 0.02	0.00
20% AEP	0.00 to 0.02	0.00
10% AEP	0.00 to 0.02	0.00
5% AEP	0.00 to 0.02	0.00
2% AEP	-0.01 to 0.03	0.00
1.33% AEP	-0.03 to 0.04	0.01
1% AEP	0.00 to 0.04	0.01
1% AEP + CC	0.00 to 0.02	0.01
0.1% AEP	-0.01 to 0.38	0.07
Storm duration of 10.00 hours:		
20% AEP	0.00 to 0.02	0.00
10% AEP	0.00 to 0.02	0.00
5% AEP	0.00 to 0.02	0.00
2% AEP	0.00 to 0.02	0.00
1.33% AEP	-0.03 to 0.03	0.01
1% AEP	-0.01 to 0.04	0.01
1% AEP + CC	-0.01 to 0.02	0.01
0.1% AEP	-0.03 to 0.46	0.08

5.3.2 The area around the Grand Union Canal crossing (Saltley Canal underbridge), see Figure 6 and Figure 7, shows an increase in flood extents and flood levels due to the inclusion of the Proposed Scheme for flood events up to 1% AEP + climate change. It is important to highlight that the estimated changes are not deemed to be representative as the model resolution does not allow the accurate representation of the ~3m wide gap between the Birmingham and Derby Line and Proposed Scheme overbridges, which is expected to allow most out-of-bank flows to closely follow the baseline route.

5.3.3 Immediately upstream of the Birmingham and Derby Line (see Volume 5: Map Book WR-05-160 G7), there is an increase in flood extent for the 1% AEP + climate change event in the post-development model. This increase in local flooding (of up to 220 mm of in depth), is a result of a 4mm rise in water level in the channel. This is a consequence of small rises in water level (likely caused by only partial representation of flow paths adjacent to Saltely Canal underbridge) propagated upstream. Due to the limitations of the model this is not deemed to be representative, at the detailed design stage, additional modelling and survey data collection will be undertaken to demonstrate this and ensure that there is no significant increase in flood risk at this location.

5.3.4 Based on peak flows, the Proposed Scheme will have a negligible impact (for return periods up to 1% AEP + climate change) confined to the relief channel. Results show changes occur between nodes 'REA01_1798D' and 'REA01_ 1139D', where flows are essentially in-bank.

Figure 6: Change in 1% AEP (without climate change) peak water levels (post-development model)

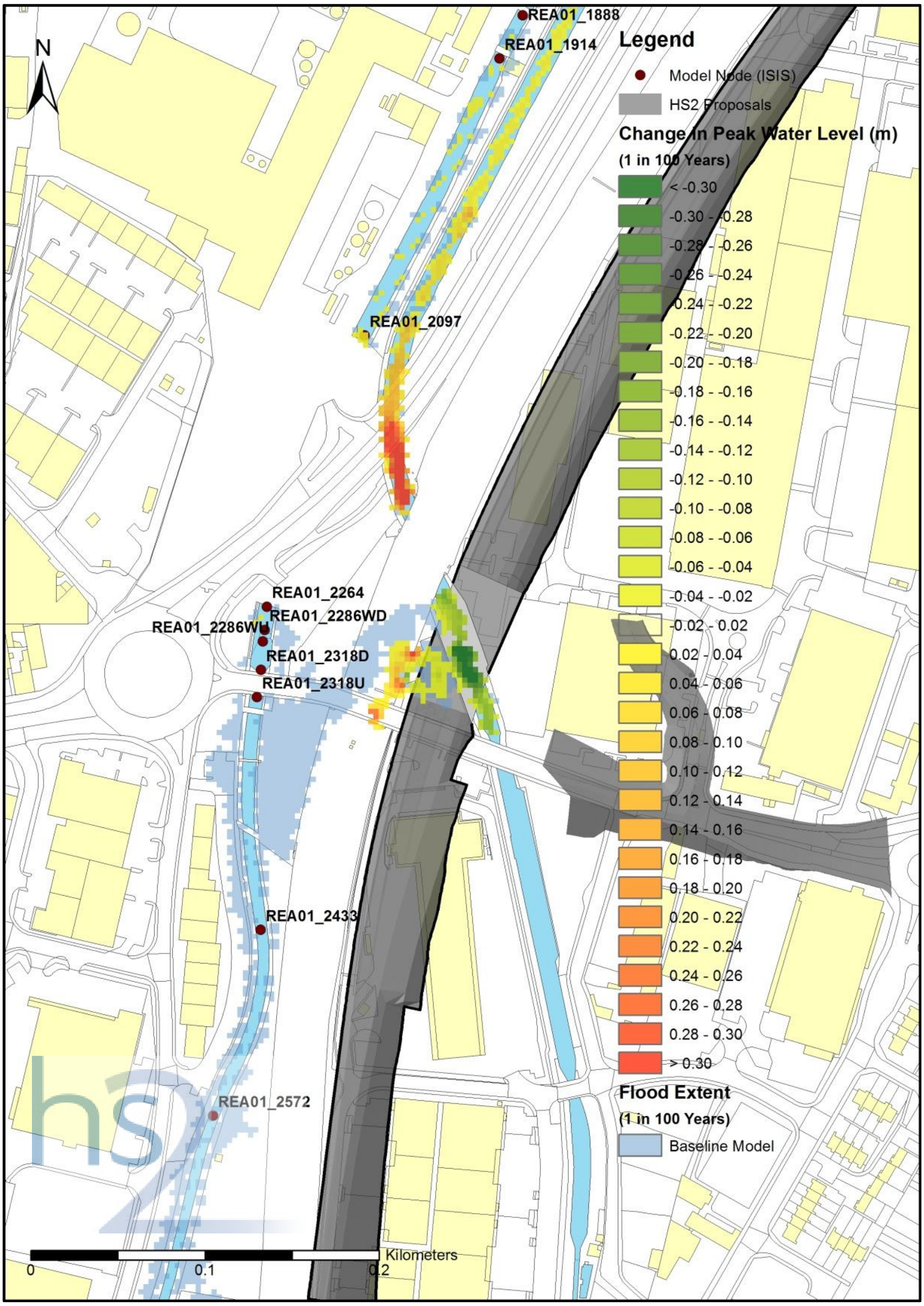


Figure 7: Change in 1% AEP (with climate change) peak water levels (post-development model)

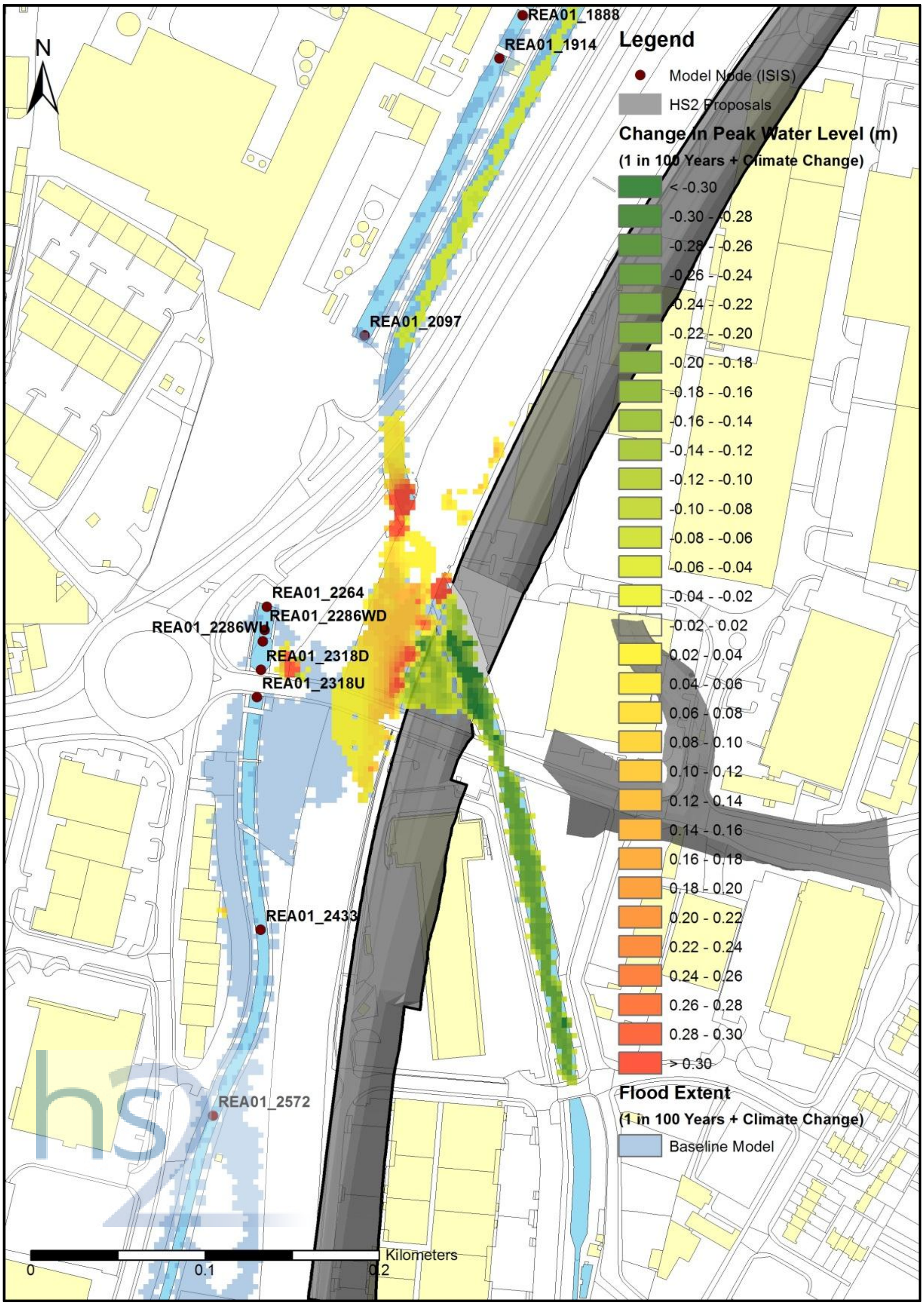


Figure 8: 1% AEP (with climate change) hydrographs at node 'REA01_1798D'

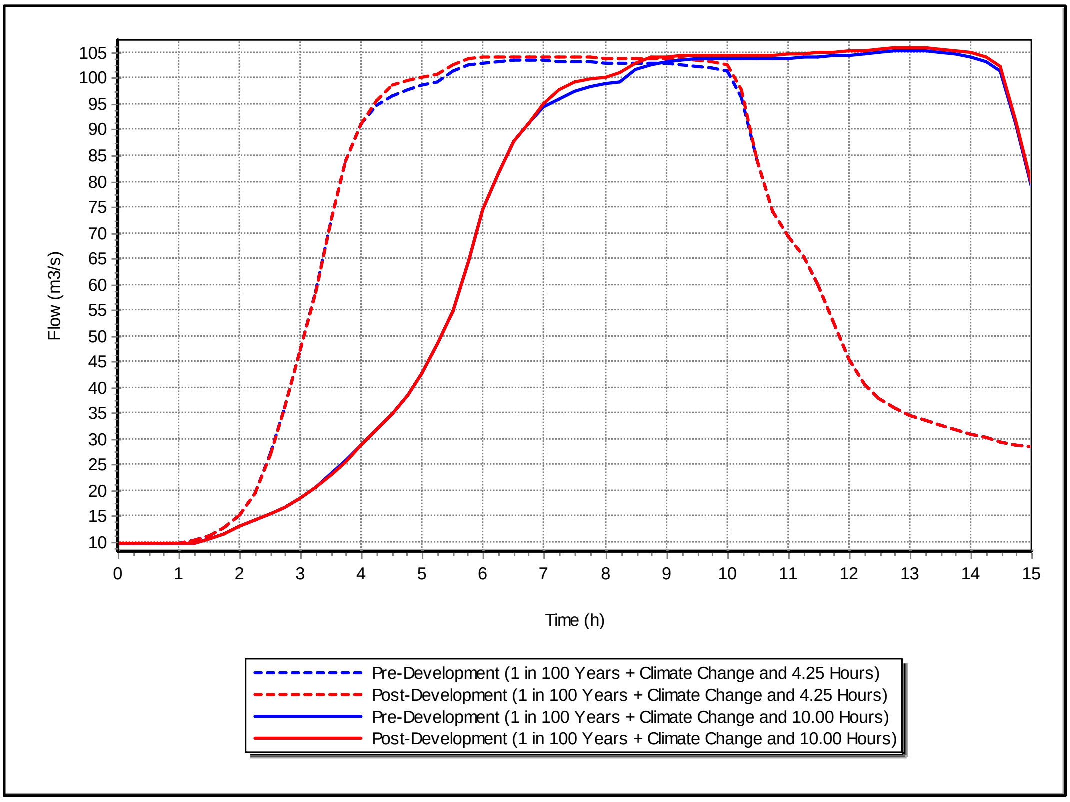
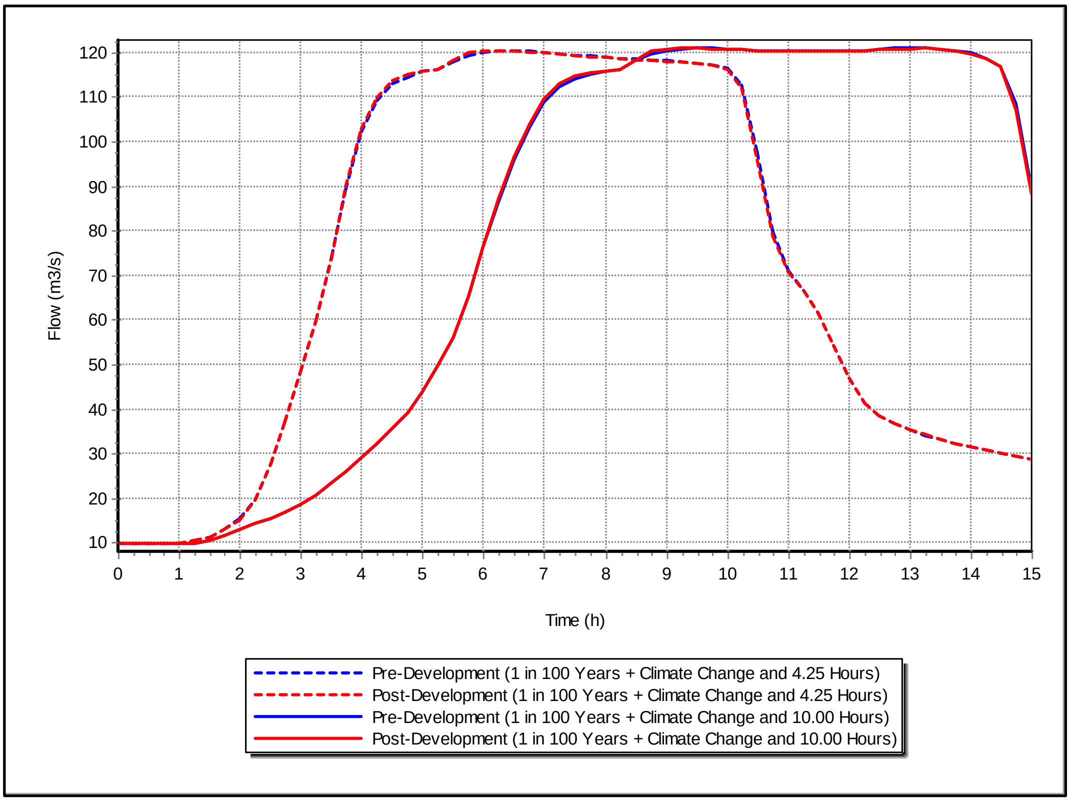


Figure 9: 1% AEP (with climate change) hydrographs at node 'REA01_1139D'



6 Calibration and sensitivity tests

6.1 Calibration

6.1.1 There is no calibration data available for the modelled reach, as Calthorpe gauging station – at the model's upstream end – is the last calibration point in the River Rea before its confluence with the River Tame. There are also no surveyed levels of flooding or historic flood outlines for the modelled reach (both Birmingham City Council's records of historic flooding and Environment Agency's outlines of historical flood events in 1992 and 2007 indicate low risk of river flooding in the area of interest).

6.1.2 In order to assess the effect of uncertainty in model assumptions, a range of sensitivity tests were undertaken for the most critical assumptions made during the model build. These are:

- roughness and weir coefficients (sensitivity tests 1 and 2);
- downstream boundary condition (sensitivity tests 3 and 4); and
- top-of-bank levels (sensitivity test 6).

6.1.3 Sensitivity tests 1 to 6 were carried out for the 1% AEP (without climate change) event with 4.25hr storm duration, while the blockage of structures (1 to 9) was assessed for the 0.1% AEP event with 10hr storm duration. Results are presented in the following sections.

6.2 Roughness and weir cooefficients (sensitivity tests 1 and 2)

6.2.1 The model's sensitivity to roughness and weir coefficients was assessed by considering ±10% variations on the adopted values (refer to Sections 4.2 and 4.3).

6.2.2 Sensitivity test 1 (ISIS file *BRUM_ST1.dat* and TUFLOW file *BRUM_ST1.tmf*) considers a 10% increase to Manning's 'n' values (in both 1D and 2D domains) and a 10% decrease to weir coefficients. As expected, these changes to roughness and weir coefficients result in higher peak water levels along the modelled reach, with an average increase in peak water level of 0.32m and a maximum increase of 0.76m.

6.2.3 Sensitivity test 2 (ISIS file *BRUM_ST2.dat* and TUFLOW file *BRUM_ST2.tmf*) considers a 10% decrease to Manning's 'n' values and a 10% increase to weir coefficients. As expected, these changes to roughness and weir coefficients result in lower water levels along the modelled reach, with an average decrease in peak water level of 0.26m and a maximum decrease of 0.54m.

6.2.4 Floodplain extents and depth results (*BRUM_ST1_0100yr_04hr_d_g003_Max.asc* and *BRUM_ST2_0100yr_ 04hr_d_g003_Max.asc*) show the model is significantly sensitive to roughness and weir coefficients. However, in the absence of accurate calibration data, the proposed coefficients, established based on site walkthroughs and photographs (SFRM model) and in line with recommended values, are deemed the most credible representation of the existing river system.

6.3 Downstream boundary conditions (sensitivity tests 3 and 4)

6.3.1 The model's sensitivity to the downstream boundary condition was assessed by considering different water levels at the confluence with the River Tame.

6.3.2 Sensitivity test 3 (ISIS file BRUM_ST3.ied) considers a constant downstream water level of 86.7m AOD (50% AEP event in the River Tame). As expected, this change to the downstream boundary condition results in lower peak water levels. Up to node REA01_2286WD (the affected area), the average decrease in peak water level is 0.10m and the maximum decrease is 1.50m.

6.3.3 Sensitivity test 4 (ISIS file BRUM_ST4.ied) considers a constant downstream water level of 89.7m AOD (0.1% AEP event in the River Tame). As expected, this change to the downstream boundary condition results in higher peak water levels. Up to node REA01_2286WD (the affected area) the average increase in peak water level is 0.20m and the maximum increase is 1.50m.

6.3.4 Results show the model has a limited sensitivity to the downstream boundary condition, with changes confined to the downstream end of the modelled reach (up to node REA01_2286WD). In the absence of a joint probability analysis to define the likelihood of extreme events happening in both rivers simultaneously, the proposed downstream water level is considered appropriate.

6.4 Top of bank levels (sensitivity test 6)

6.4.1 The model's sensitivity to top-of-bank levels was assessed by interpolating elevations between the surveyed cross-sections (similarly to the SFRM model).

6.4.2 Sensitivity test 6 (TUFLOW file BRUM_ST6.tgc) uses 'zlines' (GIS file 2D_zln_ BRUM_BankLevels.shp) to represent top-of-bank levels throughout the modelled reach. As a consequence, changes to the estimated peak water levels vary between -0.02m and 0.04m, with a negligible (~0.01m) average value.

6.4.3 Results suggest the model's sensitivity to top-of-bank levels (between the contrasting scenarios analysed) is negligible and, in the absence of more accurate information, the LiDAR based bank levels used in the baseline model are considered appropriate.

6.5 Blockage of structures

6.5.1 The model's sensitivity to blockage of structures was assessed by considering a 10% blockage of the following bridges and culverts for the 0.1% AEP event with 10hr storm duration:

- Duddeston Mill Road ('REA01_2875B' in ISIS file BRUM_B01.dat). A 10% blockage of this structure will raise peak water levels along a 747m reach (between nodes 'REA01_3622' and 'REA01_2875'), with estimated peak water levels increasing up to 0.34m (immediately upstream the structure);
- Saltley Viaduct ('REA01_2318B' in ISIS file BRUM_B02.dat). A 10% blockage of this structure will raise peak water levels along a 1,304m reach (between nodes 'REA01_3622' and 'REA01_2318U'), with estimated peak water levels increasing up to 0.34m (immediately upstream the structure);

- Heartlands Parkway ('REA01_2264B' in ISIS file BRUM_B03.dat). A 10% blockage of this culvert will raise peak water levels along a 611m reach (between nodes 'REA01_2875' and 'REA01_2264'), with estimated peak water levels increasing up to 0.13m (~22m upstream the culvert);
- waste recycling area ('REA01_1888B' in ISIS file BRUM_B04.dat). A 10% blockage of this structure will raise peak water levels along a 1,150m reach (between nodes 'REA01_3038' and 'REA01_1888'), with estimated peak water levels increasing up to 0.47m (immediately upstream the structure);
- Aston Church Road 1 ('REA01_1543B' in ISIS file BRUM_B05.dat). A 10% blockage of this structure will raise peak water levels along a 1,332m reach (between nodes 'REA_2875' and 'REA_1543'), with estimated peak water levels increasing up to 0.32m (immediately upstream the structure);
- Watson Road ('REA01_1139B' in ISIS file BRUM_B06.dat). A 10% blockage of this structure will raise peak water levels along a 1,736m reach (between nodes 'REA_2875' and 'REA_1139'), with estimated peak water levels increasing up to 0.58m (~17m upstream the structure);
- Washwood Heath ('REA01_443B' in ISIS file BRUM_B07.dat). A 10% blockage of this culvert will raise peak water levels along a 2,432m reach (between nodes 'REA_2875' and 'REA_443'), with estimated peak water levels increasing up to 0.55m (~362m upstream the culvert);
- Aston Church Road 2 ('ROF_0380B' in ISIS file BRUM_B08.dat). A 10% blockage of this culvert will raise peak water levels along a 629m reach (between nodes 'ROF_0710' and 'ROF_0380' and 'REA_2097' and 'REA_ 1798U'), with estimated peak water levels increasing up to 0.18m (immediately upstream the culvert);
- Grand Union Canal (GIS files 1D_nwk_BRUM_B09.shp and 2D_lfc_ BRUM_B09.shp). A 10% blockage of these overbridges will raise peak water levels along a 1,724m reach (between nodes 'REA01_1914' and 'REA01_190') and the whole relief channel, with estimated peak water levels increasing up to 0.07m (within the relief channel).

7 Model limitations

7.1.1 Table 5 shows the limitations which have been identified for the pre- and post-development models described in the sections above.

Table 5: Model limitations

Limitation	Risk assessment	Mitigation	Comments/Actions
Culverts were modelled considering that their surveyed section shape (generally the upstream face) remains constant through the entire conduit.	Medium/High	-	CCTV survey of the longer culverts within the area of interest is recommended to improve the quality and accuracy of model data.

Limitation	Risk assessment	Mitigation	Comments/Actions
The two storm durations adopted are appropriate for the catchment but may not necessarily represent the critical storm duration for all scenarios or return periods. Model results appear to be relatively insensitive to storm duration with the exception of the 1% AEP plus cc event. Further analysis of storm duration should be undertaken in future stages of the project	Medium	Refer to Section 4.8	Further analysis should be undertaken in future stages of the project. Defining the critical storm duration appears particularly important for the 1% AEP (with climate change) event.
Without the benefit of a joint probability study, it is not possible to define the likelihood of extreme events happening in the Rea and Tame rivers simultaneously.	Low	Sensitivity tests 3 and 4	Results show the model has a limited sensitivity to the downstream boundary condition, with changes confined to the downstream end of the modelled reach. In the absence of a joint probability analysis the proposed downstream water level is considered appropriate.
The representation of bank levels in the model has been improved using the best available data but further accuracy could be achieved by undertaking bank top survey, which is recommended for future stages of the project.	Low	Sensitivity test 6	Results suggest the model's sensitivity to top-of-bank levels (between the contrasting scenarios analysed) is negligible and, in the absence of more accurate information, the LiDAR based bank levels used in the baseline model are considered appropriate.
Results (sensitivity tests 1 and 2) show the model is significantly sensitive to roughness and weir coefficients.	High	Sensitivity tests 1 and 2	In the absence of accurate calibration data, the proposed coefficients, established based on site walkthroughs and photographs and in line with recommended values are deemed the most credible representation of the existing river system. The collection of calibration data for future stages of the project is strongly recommended.
Model insufficiently detailed to accurately represent very localised effects of Proposed Scheme infrastructure such as representation of the gap between the NR and Proposed Scheme overbridges.	Low	Model provides conservative estimate of flood risk impacts due to Proposed Scheme here	Further data collection and localised refinements to model to more accurately represent flow mechanisms at this location.

8 References

Royal Haskoning, (2010), River Rea Strategic Flood Risk Mapping (SFRM) model, Environment Agency

Maltby Land Surveys, (2008), River Rea survey

Birmingham City Council, (2012), River Rea overflow

9 Annex A – Review of SFRM hydrology

9.1 Introduction

9.1.1 On the 13th June 2012 the Environment Agency's existing river hydraulic model of the River Rea was obtained. This consisted of a 1D-2D ISIS-Tuflow river hydraulic model developed to provide a catchment wide of perspective on flood risk.

9.1.2 This model has been reviewed, checked and updated for use in assessing the Proposed Scheme design activities affecting the River Rea.

9.2 Existing hydrology inputs

9.2.1 The derivation of the input hydrology followed the methodology set out below:

- the River Rea catchment defined up to Calthorpe gauging station using flood estimation handbook (FEH) CD Rom v2;
- catchment verified and adjusted where necessary using available LiDAR;
- catchment average rainfall calculated using the thiessen polygon method based on rainfall data collected at three rainfall gauges across the catchment at Frankley, Waseley and Saltley;
- Calthorpe gauging station rating compared to stage – discharge results generated by the hydraulic model to ensure the two agreed with each other;
- event analysis undertaken on three high flow events at Calthorpe gauging station (June 2003, June 2007 and October 2008) based on observed flow/level and rainfall data. This allowed derivation of event specific hydrographs and unit hydrographs;
- a theoretical unit hydrograph was then generated using the FEH rainfall runoff method for the River Rea up to Calthorpe gauging station; and
- the theoretical unit hydrograph for Calthorpe gauging station was then adjusted based on the unit hydrographs developed for the observed events. This was done by scaling the time to peak (T_p) , the flow per unit of rain (U_p) and the time base (TB) to match the observed unit hydrographs.

9.2.2 This resulted in the existence of 5 unit hydrographs for Calthorpe gauging station:

- unit hydrograph for June 2003 event;
- unit hydrograph for June 2007 event;
- unit hydrograph for October 2008 event;
- theoretical FEH unit hydrograph; and
- scaled theoretical unit hydrograph;

9.2.3 Each unit hydrograph (described above) was then used as the basis of a FEH boundary inflow within ISIS to generate the 50% AEP flood with a Qmed rainfall for Calthorpe gauging station.

9.2.4 This established that the scaled theoretical unit hydrograph was best able to replicate the observed Qmed flow calculated for Calthorpe gauging station (31.91 m^3/s). Therefore, the factors used to derive the scaled theoretical unit hydrograph were applied to all the inflows within the hydrological model except for an inflow at Bartley reservoir. As this is a rural catchment the theoretical unit hydrograph without any adjustments was applied.

9.2.5 This process derived peak flows and hydrographs for each inflow location within the hydrological model and for Calthorpe gauging station. The peaks flows for Calthorpe gauging station are shown in Table 6 while the inflows derived for each inflow location within the hydraulic model are indicated in Table 7.

Table 6: Initial flows derived for Calthorpe gauging station

AEP	Flow (m^3/s)
Qmed	31.91
4% AEP	76.53
2% AEP	93.38
1.33% AEP	103.78
1% AEP	111.27
1% AEP plus climate change	133.53
0.5% AEP	132.83
0.1% AEP	205.88

Table 7: Initial flows derived for each model inflow location

Inflow	Qmed	4% AEP	2% AEP	1.33% AEP	1% AEP	1% AEP plus climate change	0.5% AEP	0.1% AEP
Rea01_20299a	1.6	3.44	4.24	4.85	5.33	6.39	6.66	11.2
Lat 8	2.93	6.29	7.76	8.85	9.7	11.64	12.08	20.16
Lat 7	3.02	6.49	8.01	9.13	10	12	12.45	20.75
Lat6	3.27	7.06	8.7	9.92	10.87	13.05	13.53	22.56
latRea	2	4.31	5.32	6.07	6.65	7.98	8.27	13.81
GriffBk	1.97	4.24	5.25	6.01	6.6	7.92	8.26	13.97
WoodBk	1.14	2.63	3.24	3.66	4.07	4.88	5.15	8.9
LatThe Bourn	1.52	3.3	4.09	4.68	5.14	6.16	6.42	10.83
BartRes	0.77	1.82	2.26	2.51	2.69	3.23	3.22	4.98
UpBournBK	2	4.37	5.42	6.19	6.8	8.16	8.5	14.34
Lat5	1.6	3.46	4.28	4.89	5.37	6.45	6.72	11.31

Inflow	Qmed	4% AEP	2% AEP	1.33% AEP	1% AEP	1% AEP plus climate change	0.5% AEP	0.1% AEP
Lat4	3.1	6.75	8.33	9.52	10.45	12.54	13.06	21.96
Lat3	2.05	4.45	5.5	6.29	6.9	8.28	8.62	14.49
BournNside	3	6.55	8.07	9.24	10.15	12.18	12.69	21.4
Lat2	2.5	5.39	6.63	7.58	8.32	9.98	10.38	17.43
Lat1	2.69	5.8	7.14	8.15	8.95	10.74	11.17	18.74
Lat0	1.53	3.31	4.08	4.66	5.11	6.13	6.37	10.69

9.2.6 Before the river hydraulic model was used to simulate the design flows experienced along the River Rea it was calibrated against the same events used to derive thee initial design flow hydrographs (June 2003, July 2007 and September 2008).

9.2.7 As part of calibration process the percentage runoff value used by each inflow was adjusted from between 30 – 40% to between 65 – 75% to reflect the urbanised nature of the Rea catchment. It is not clear why this adjustment was not implemented during derivation of the initial flow hydrographs.

9.2.8 By increasing the percentage runoff values the flows at each inflow location increased significantly.

9.2.9 The calibration runs generated water levels that were 500mm greater that observed water levels for the June 2003 event. The modelled water levels for the July 2007 event were 250mm greater that the observed levels. However, the modelled levels generated for the September 2008 event were a good match to observed level.

9.2.10 On the basis of the September 2008 calibration event the increased percentage runoff figure was adopted

9.2.11 The 'final flows' for each inflow location are shown in Table 8.

Table 8: Final flows derived for each model inflow location

Inflow	Qmed	4% AEP	2% AEP	1.33% AEP	1% AEP	1% AEP plus CC	0.5% AEP	0.1% AEP
Rea01_20299a	3.06	6.6	8	8.95	9.69	11.63	11.71	18.22
Lat 8	5.42	11.68	14.16	15.83	17.13	20.56	20.73	32.25
Lat 7	5.03	10.86	13.16	14.72	15.93	19.12	19.29	30.04
Lat6	5.53	11.96	14.5	16.23	17.58	21.09	21.29	33.22
latRea	3.33	7.19	8.73	9.77	10.57	12.69	12.81	19.99
GriffBk	3.53	7.64	9.28	10.38	11.25	13.5	13.63	21.3
WoodBk	1.99	4.55	5.59	6.3	6.86	8.24	8.42	13.53
LatThe Bourn	2.6	5.67	6.89	7.71	8.36	10.03	10.14	15.88

Inflow	Qmed	4% AEP	2% AEP	1.33% AEP	1% AEP	1% AEP plus CC	0.5% AEP	0.1% AEP
BartRes	2.11	4.83	5.69	6.22	6.6	7.92	7.67	11.09
UpBournBK	3.63	7.95	9.66	10.83	11.74	14.08	14.25	22.35
Lat5	2.89	6.28	7.63	8.55	9.26	11.11	11.23	17.56
Lat4	5.41	11.8	14.35	16.07	17.42	20.9	21.14	33.13
Lat3	3.51	7.65	9.3	10.42	11.29	13.55	13.71	21.48
BournNside	5.15	11.25	13.68	15.33	16.62	19.94	20.17	31.65
Lat2	4.19	9.07	11.02	12.34	13.36	16.04	16.21	25.36
Lat1	4.4	9.53	11.58	12.96	14.05	16.86	17.04	26.68
Lat0	2.47	5.35	6.5	7.28	7.88	9.46	9.56	14.98

9.3 Assessment of hydrology Inputs

9.3.1 It is stated in the both the South Birmingham hazard mapping interim hydrology report and the South Birmingham hazard mapping final modelling report authored by Royal Haskoning that a good agreement was attained between the statistically derived Qmed value derived AMAX values at Calthorpe and the peak flow generated for a 50% AEP event and a Qmed rainfall event using their 'adjusted unit hydrograph' generated based on observed data.

9.3.2 On this basis the initial design flow estimates for a range of return periods were generated using the adjusted unit hydrograph. However, these initial design inflows have then been amended by adjusting the percentage runoff value used for each inflow to reflect the urbanisation of the Rea catchment. This percentage runoff adjustment has been used to derive the final design flows used in the simulations.

9.3.3 The final design flows are approximately 50% greater than the initial design flows. Therefore, it is assumed that if the adjusted percentage runoff value is used to derive a Qmed hydrograph at Calthorpe gauging station (using the adjusted Unit Hydrograph) this would be significantly greater than the Qmed calculated based on observed data.

9.3.4 However, if the design flows recorded at Calthorpe gauging station by the river hydraulic model and the initial flows derived from the adjusted unit hydrograph for Calthorpe are compared (see Table 9) it is clear that there is a reasonable level of agreement. The model had not originally simulated the Q med or the 4% AEP flow.

Table 9: Initial flows generated for Calthorpe compared against flows recorded at Calthorpe using final inflows

	Initial Rainfall Runoff Flow (m^3/s)	Flow recorded at Calthorpe using final design inflows (m^3/s)	Difference (%)	Difference (m^3/s)
Qmed	31.9	no simulation done	-	-
4% AEP	76.5	no simulation done	-	-

	Initial Rainfall Runoff Flow (m^3/s)	Flow recorded at Calthorpe using final design inflows (m^3/s)	Difference (%)	Difference (m^3/s)
2% AEP	93.4	91.9	1.5	1.6
1.33% AEP	103.8	98.6	5.1	5.0
1% AEP	111.3	102.2	9.1	8.1
0.5% AEP	132.8	123.5	9.3	7.0
0.1% AEP	205.9	164.4	41.4	20.1

9.3.5 This indicates that the flows reaching Calthorpe gauging station as indicated by the river hydraulic model are within 10% of the initial design flows for all return periods. However there is a 20% deviation for the 0.1% AEP.

9.4 Conclusions

9.4.1 The final design inflows are significantly greater than the flows calculated as part of the 2009 interim hydrology report. The basis of the increased inflow values are increased percentage runoff values incorporated into the rainfall runoff model which give a good agreement to an observed event in September 2008. In addition, the flows recorded within the model simulations at Calthorpe gauging station are a reasonable match to the initial design flows calculated at Calthorpe. On this basis the inflow hydrology to the River Rea river hydraulic model has not been revised.